ECOSYSTEM STATUS INDICATORS
Physical Environment

Ecosystem Indicators and Trends Used by FOCI
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FOCI's scientists employ a number of climate, weather, and ocean indices and trends to help describe and ascribe the status of the ecosystem to various patterns or regimes. This document presents some of these with respect to current (2004) conditions. This section begins with an overview of North Pacific climate for 2004, including an examination of trends and tendencies in multidecadal and decadal climate regimes. Following this section are sections dealing explicitly with the western Gulf of Alaska and eastern Bering Sea. Within these are continuations of discussions begun in 2003 on eddy kinetic energy in the Gulf of Alaska and modeled drift trajectories for the Bering Sea.

Pacific Climate Overview – 2005
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Summary*. The winter of 2005 was characterized by atmospheric circulation anomalies that little resembled leading teleconnection modes. There was a weak El Niño event, but it had either a minor or atypical impact on the North Pacific. The PDO index was positive, suggesting that the climate regime established since the late 1970s still continues, but the distribution of sea surface temperature (SST) in the North Pacific did not closely correspond with the PDO loading pattern. The characteristic features of this distribution were a warm water pool in the east-central North Pacific and patchiness of SST anomalies elsewhere. The SST-based Victoria pattern, after being in its positive phase during 1999-2004, showed a sign of reversal in 2005. It was not consistent, however, with its atmospheric counterpart, a north-south dipole in sea level pressure (SLP). Instead, the anomalous SLP in 2005 featured an east-west dipole consisting of a negative anomaly centered along 170˚W from 40˚N into the Bering Sea, and a positive anomaly in the eastern Pacific from 40˚N into the Gulf of Alaska. This combination brought about southerly wind anomalies and an enhancement of cyclonic activity for the Bering Sea shelf, and a suppression of storminess in the eastern North Pacific.*

Climate in 2005
It is in the human nature to search for patterns, but it is difficult to characterize the winter of 2005 in terms of previously identified patterns of variability. In other words, it seems easier to describe this winter climate by what it was not. It was not a winter of a distinct El Niño-Southern Oscillation (ENSO) event. The distribution of sea-surface (SST) temperature anomalies in the North Pacific was neither the Pacific Decadal Oscillation (PDO), nor the Victoria patterns, and the Arctic Oscillation (AO) index was in the neutral phase, overall.

The Southern Oscillation Index (SOI) was negative in all months from June 2004 to June 2005, except January 2005 (Figure 1), and SST anomalies in the Niño 3.4 region in the central equatorial Pacific exceeded 0.5°C (Figure 2). It was enough to qualify as an El Niño event by some definitions, but it was in a weak category and accompanied by a number of uncharacteristic features. First, it did not extend all the way to West Coast of South America (Niño 1+2 region) where SST anomalies were predominantly negative (Figure 2). Second, there was a lack of persistent enhanced convection over the anomalously warm waters of the central equatorial Pacific, which has limited El Niño-related impacts on the global circulation patterns. For example, a weaker than average jet stream across the central and eastern Pacific in the winter of 2005 is inconsistent with El Niño.

The Aleutian low was stronger than normal and the PDO index, as expressed by the PC1 in Figure 3 (bottom panel), was positive, but the distribution of SST anomalies in the North Pacific (Figure 4) had little resemblance with the PDO loading pattern (Figure 3 upper panel). The characteristic features of this distribution in winter 2005 were a warm water pool in the east-central North Pacific and patchiness of SST anomalies elsewhere. Later, in spring and summer of 2005, the warm waters spread to the east, closer to the North American west coast, and negative SST anomalies in the western and central North Pacific became more pronounced. As a result, the whole pattern became much more like the positive phase of the PDO, and the PDO index values jumped above one standard deviation for the months from March through June.

The resemblance of the SST anomaly distribution in the winter of 2005 to the negative phase of the Victoria pattern (EOF2 in Figure 3) is somewhat greater than with the PDO, largely due to the heavy weight of the positive SST anomaly in the east-central North Pacific. The PC2 (EOF2) value in 2005 was negative for the first time since the shift in this pattern to the positive phase in 1999. The distribution of sea-level pressure (SLP) in the winter of 2005 (Figure 5), however, did not exhibit the north-south dipole pattern characteristic of the Victoria pattern. As in the previous seven years, SLP anomalies over the Bering Sea continue to be negative, indicating enhanced cyclonic activity there.

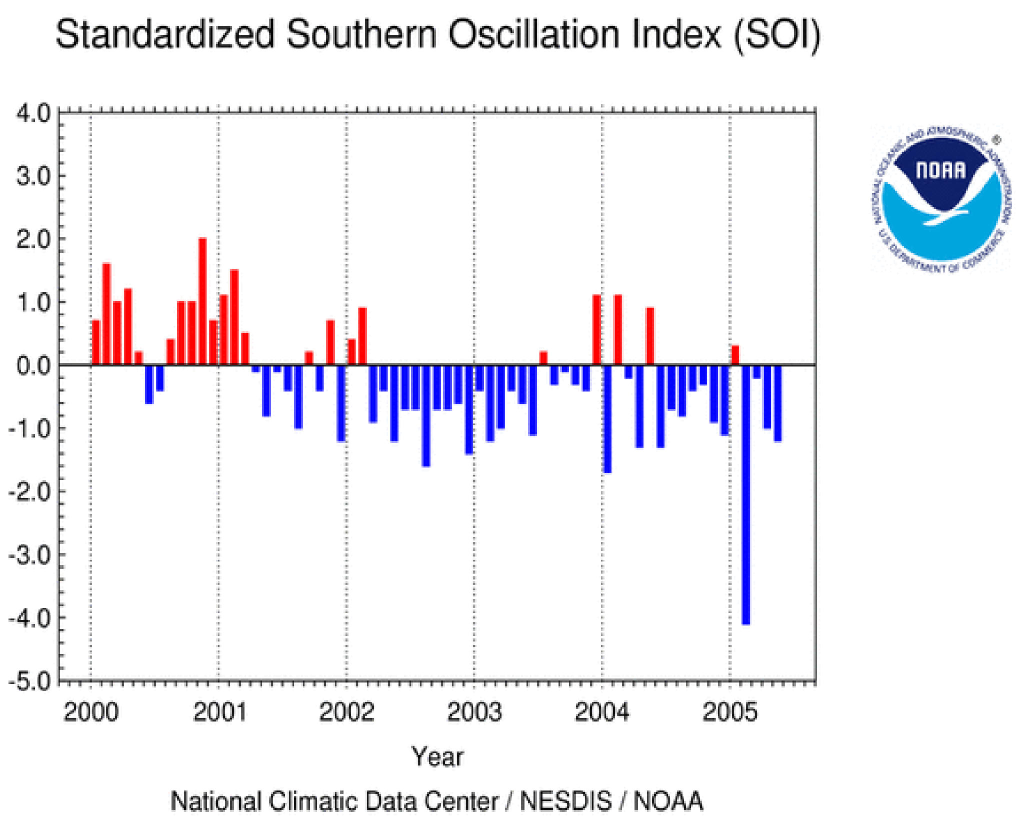


Figure 1. Mean monthly values of the Southern Oscillation Index, January 2000 through May 2005.

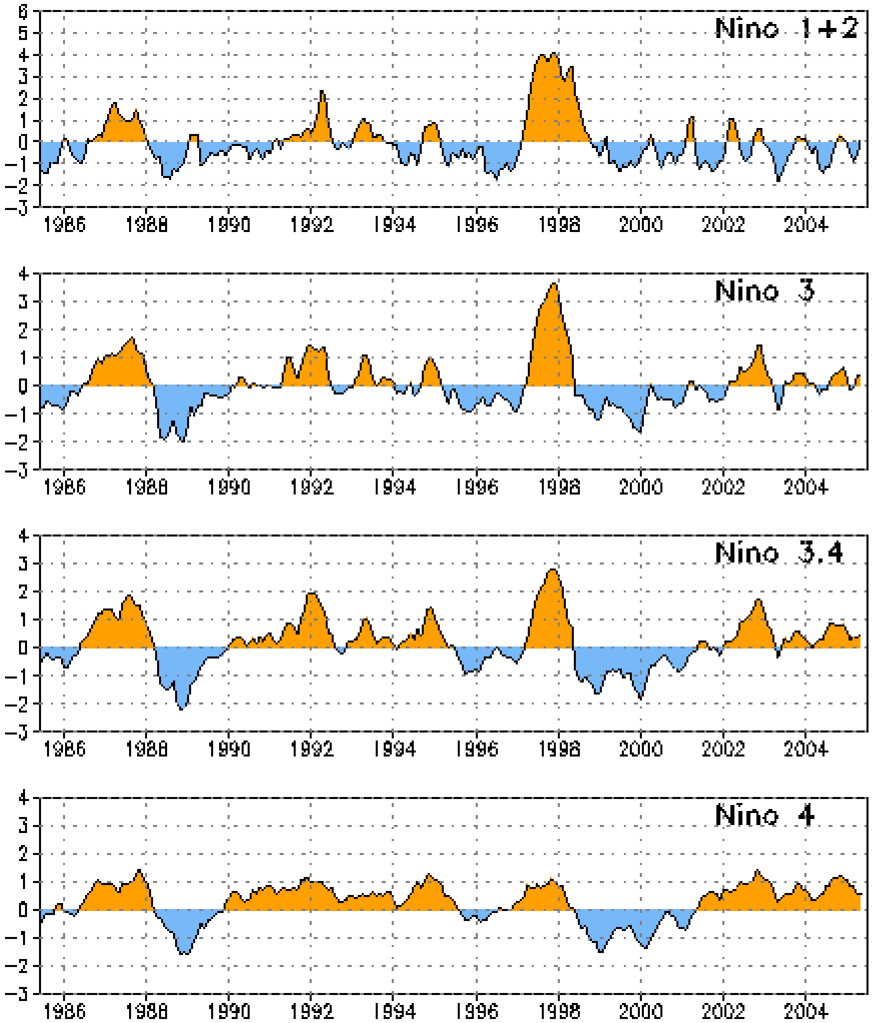


Figure 2. SST anomalies (deg. C) along the west coast of South America (Nino 1+2 region) and central parts of the equatorial belt (Nino 3, 3.4, and 4 regions), 1985-2005.

One of the most salient features of the atmospheric circulation over the North Pacific in the winter of 2005 was a strong and persistent high pressure cell off British Columbia. It split the North Pacific storm track redirecting storms either to the Bering Sea or southern California. During this winter, the Pacific Northwest (which includes Washington, Oregon, and Idaho) received only 6.23 inches of precipitation making it the fifth driest winter on record since 1896. In contrast, storms were bringing heavy rain to southern California triggering mudslides and washing away roads and runways. Los Angeles, for example, received a total of 19.58 inches of rain from December 2004 to February 2005, which makes this winter the forth wettest since 1945.

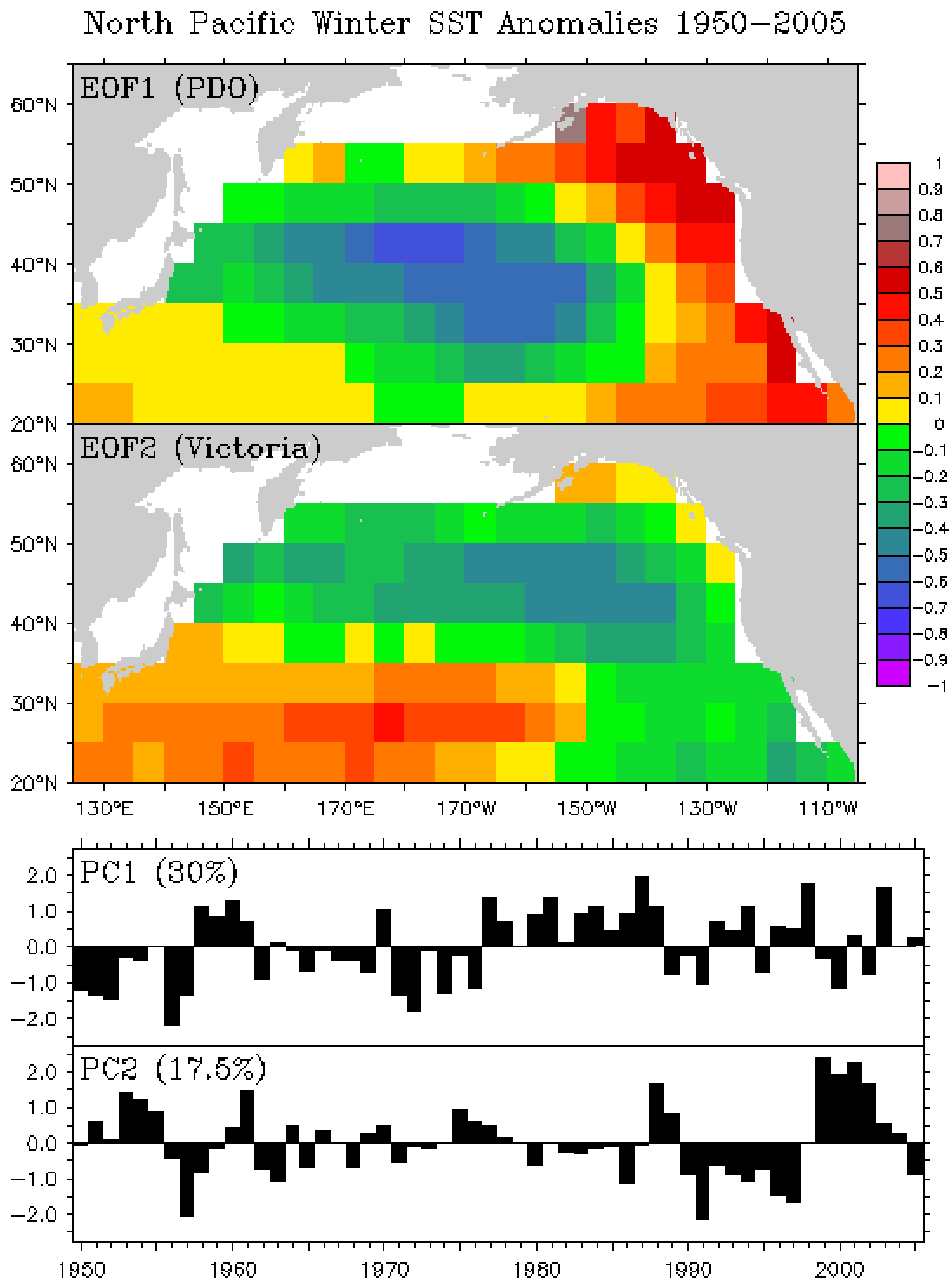


Figure 3. The first (PDO) and second (Victoria) empirical orthogonal functions of mean winter (Nov-Mar) SST anomalies in the North Pacific along with the time series of their principal components.

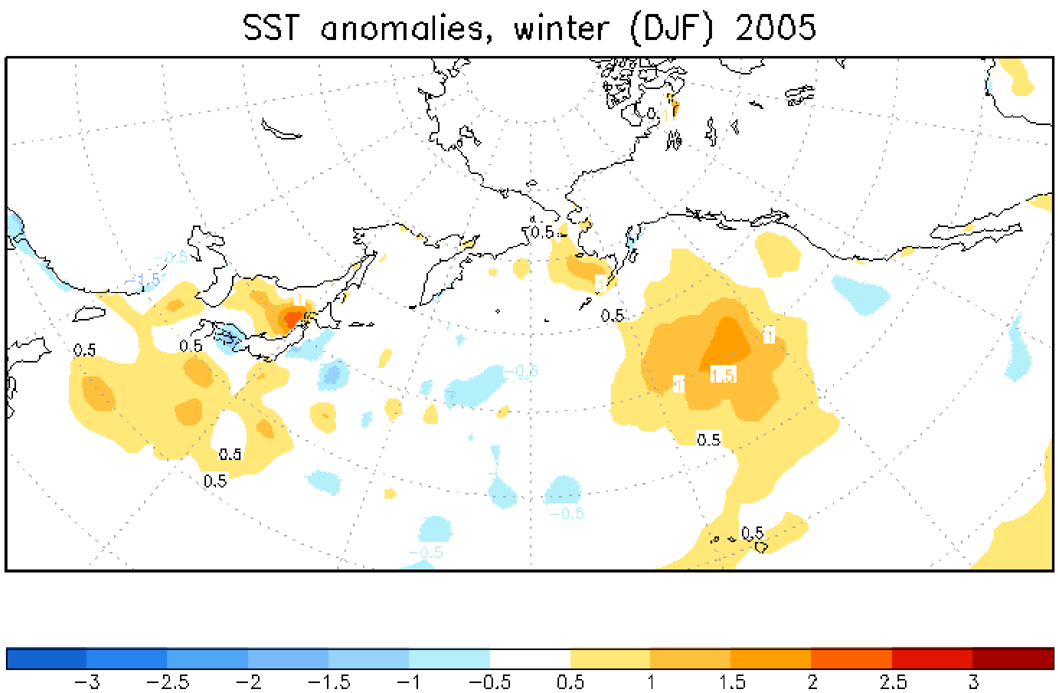


Figure 4. Mean seasonal SST anomalies in the winter (DJF) of 2005. Anomalies are relative to the 1971-2000 base period. Source data: NOAA OI.v2 SST monthly fields.

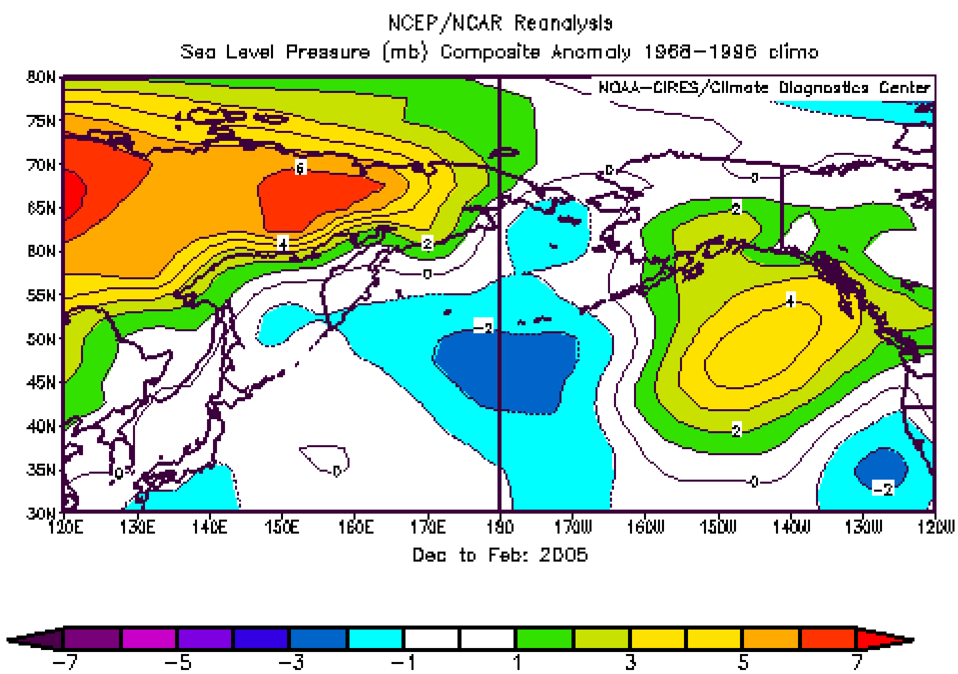


Figure 5. Mean seasonal SLP anomalies in the winter (DJF) of 2005. Anomalies are relative to the 1968-1996 base period.

The atmospheric circulation anomalies during the first half of 2005 appear to be linked to major disruptions in the marine ecosystem off the west coast of the U.S. The combination of higher than normal SLP to the northwest of Vancouver Island, and lower than normal SLP to the west of California during early 2005 (Figure 5) implies easterly wind anomalies, and in turn, anomalous poleward Ekman transports in the upper ocean off the coast of Oregon and Washington. This set of conditions was followed in spring and summer by lower than normal SLP off the U.S. west coast, leading to a delayed onset and a decreased intensity to coastal upwelling. The anomalous atmospheric forcing in winter and spring/early summer appears to have had substantial biological impacts in the northern portion of the California Current system, namely, a reduction in primary productivity, low zooplankton concentrations, and unusually high mortality rates for juvenile salmon and sea birds.

Recent Trends

The value of the winter PDO index in 2005 was close to the mean value of the index for the period since 1977 (Figure 6a). Although there were episodic excursions of the index into the negative territory, such as in 1989-1991 and 1999-2000, none of them materialized into a major regime shift similar in scale to those in the mid-1940s and late 1970s.

The summer (Figure 6b) and annual (Figure 6c) PDO index experienced a longer period of negative values since 1999, and there is the potential for a new regime shift. On the other hand, strongly positive values of the index in March-June 2005 suggest that the test for a regime shift based on the sequential algorithm (Rodionov 2005) will likely fail to support the regime shift in the late 1990s any longer.

Variations in the North Pacific Index (NPINCAR in Figure 6d, which measures the strength of the Aleutian low, is similar to those in the winter PDO index, particularly in the later part of the record. The correlation coefficient between the two is -0.72 for the period 1950-2005. The NPINCAR also shows no major regime shifts since 1977.

The lack of major regime shifts since the late 1970s does not mean that the climate remained the same throughout all this period. To investigate shorter-term, but sustained fluctuations in the system, the sequential method was applied to a number of climate indices, using a smaller cutoff length of 7 years. Figure 7a shows that the Aleutian low was the strongest for about a decade immediately following the regime shift in the late 1970s. Interestingly, the variability of the NPINCAR during that decade also increased. Occasional positive values of the index, however, did not seem to have had much effect on the North Pacific SST pattern, as expressed by the PDO index, which remained positive almost all this time (Figure 7b). In the late 1980s, the Aleutian low weakened substantially (the shift of 1988 is significant at $p = 0.02$), and the PDO index returned to its near-normal value. Later the Aleutian low strengthened again (the shift of 1996 is significant at $p = 0.04$), but not as much as in 1977-1987. The PDO index continued to fluctuate around its zero value until 2003, when it jumped to its highest value since 1941 signaling a possibility of a new regime shift.

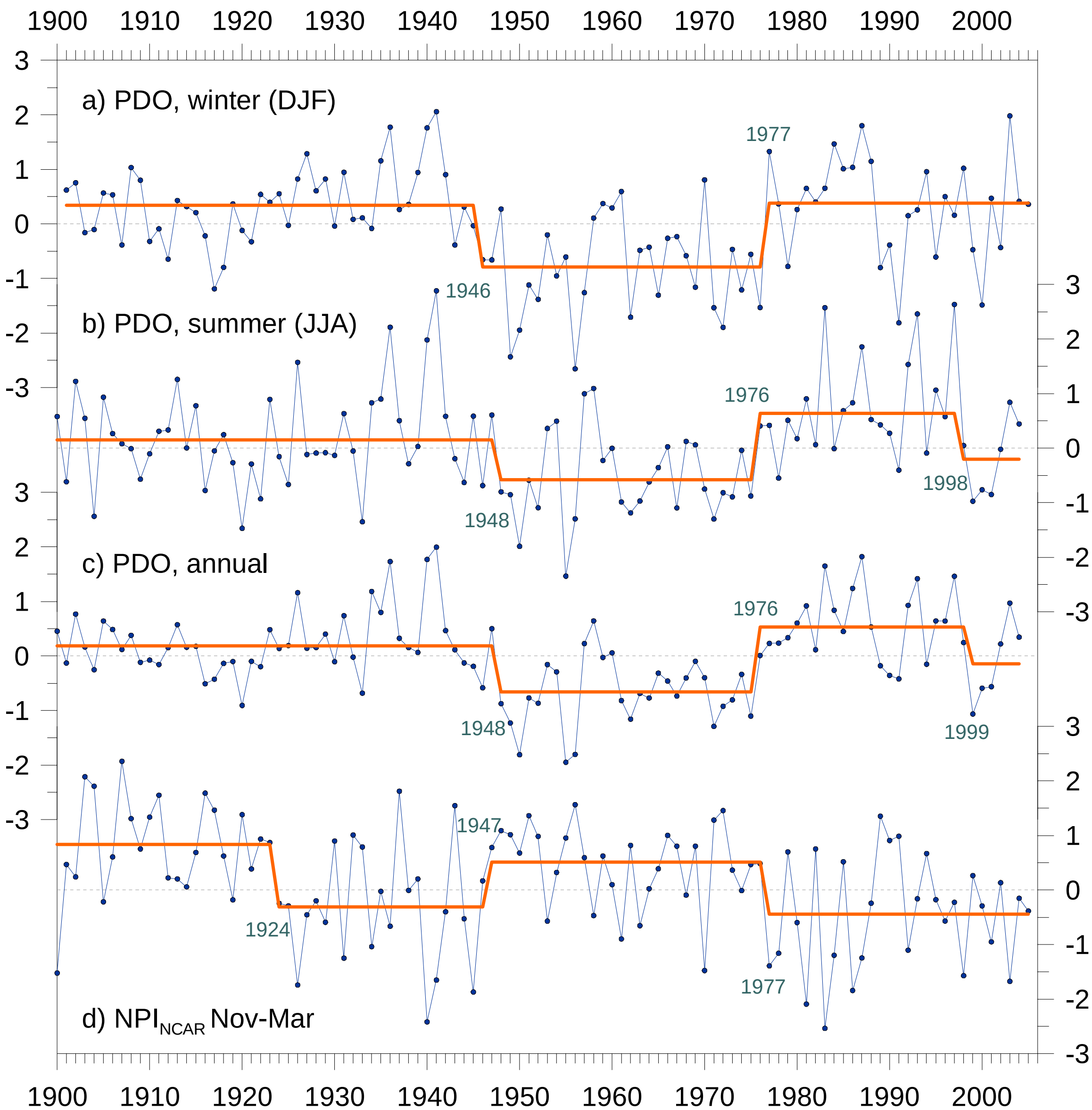


Figure 6. a) Mean winter (DJF) PDO index, 1901-2005, b) mean summer (JJA) PDO index, 1900-2004, c) Annual (Jan-Dec) PDO index, 1900-2004, and d) North Pacific index (Nov-Mar) from the National Center for Atmospheric Research, 1900-2005. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the indices. Shift points were calculated using the STARS method (Rodionov 2004), with the cutoff length of 15 years, the maximum significance level of 0.05, and the Huber weight function value of 1. The actual significance levels of the shifts are less than 0.0005.

The shift of the late 1980s was recorded in a number of fish stocks (McFarlane et al. 2000; Hare and Mantua 2000). As for the climate indices, the shift was particularly strong in the AO index that jumped to its record level in 1989 (Figure 7c). This state of highly positive AO index continued for 5 years. Since 1994 the index has fluctuated around its zero value.

Bond et al. (2003) argue that Pacific climate variability in recent years was associated primarily with the Victoria pattern, rather than with the PDO. This is clearly seen in Figure 3 (bottom panel) where the PC1

(PDO) time series fluctuated around its zero value since the late 1980s, whereas the PC2 (Victoria) values were consistently negative in 1988-1997 and consistently positive in 1999-2004. To determine the atmospheric counterparts of the PDO and Victoria pattern, the PC1 and PC2 time series were correlated against geopotential height values at the 500-hPa level. Figure 8a shows that, over the North Pacific, the PDO is characterized by a dipole with the positive center at 15˚N, 180 and the negative center at 45˚N, 165˚W. This dipole practically coincides with the oceanic centers of the Pacific/North American (PNA) pattern. The atmospheric counterpart of the Victoria pattern is also a dipole with the centers at 30˚N, 165˚W and 60˚N, 165˚W (Figure 8b). The Victoria dipole is, practically, in quadrature with the PDO dipole.

The atmospheric PDO and Victoria indices are presented in Figure 7d and Figure 7e, respectively. The indices are calculated as the normalized differences in 500-hPa height anomalies in the positive and negative centers of the respected dipoles. The atmospheric PDO index correlates with its oceanic counterpart at r = 0.83; it also exhibits shifts in 1977 and 1989, but not in 2003. The correlation coefficient between the atmospheric and oceanic Victoria indices is r = 0.78. The regime of negative index values in 1990-1997, which is clearly seen in PC2 time series (Figure 3), is not statistically significant in the atmospheric Victoria index. The only statistically significant regime-like feature in the latter index is a sequence of positive values in 1998-2002. Neither the PDO nor the Victoria indices can fully explain an abrupt shift to warmer conditions in the Bering Sea since 2000 (see the Bering Sea section).

In order to capture the part of atmospheric circulation in Figure 5 relevant to the Bering Sea, we calculated an index that represents a difference in SLP between two areas, 45-60˚N, 130-150˚W and 40-65˚N, 160-180˚W, normalized by its standard deviation. The positive (negative) values of this East-Central North Pacific (ECNP) index indicate positive (negative) east-west SLP gradient and predominantly southerly (northerly) winds over east-central North Pacific and the Bering Sea. The ECNP index does not correlate with the PDO or the Victoria indices. It is interesting, however, that all 20 positive values of the index since 1970 coincide with positive values of either the PDO or Victoria indices. It is important to underscore that the ECNP index does not represent a major mode of climate variability, such as the PDO or Victoria patterns. Instead, it appears to capture the essential elements of both these patterns pertinent to warming in the Bering Sea. The time series of the ECNP index for January-February is shown in Figure 7. The index is almost the same if averaged over the entire winter season, December through March. However, the shift in 2000 is most significant for the January-February index. As shown in the Bering Sea section, this year marks the beginning of a warm period in the sea.

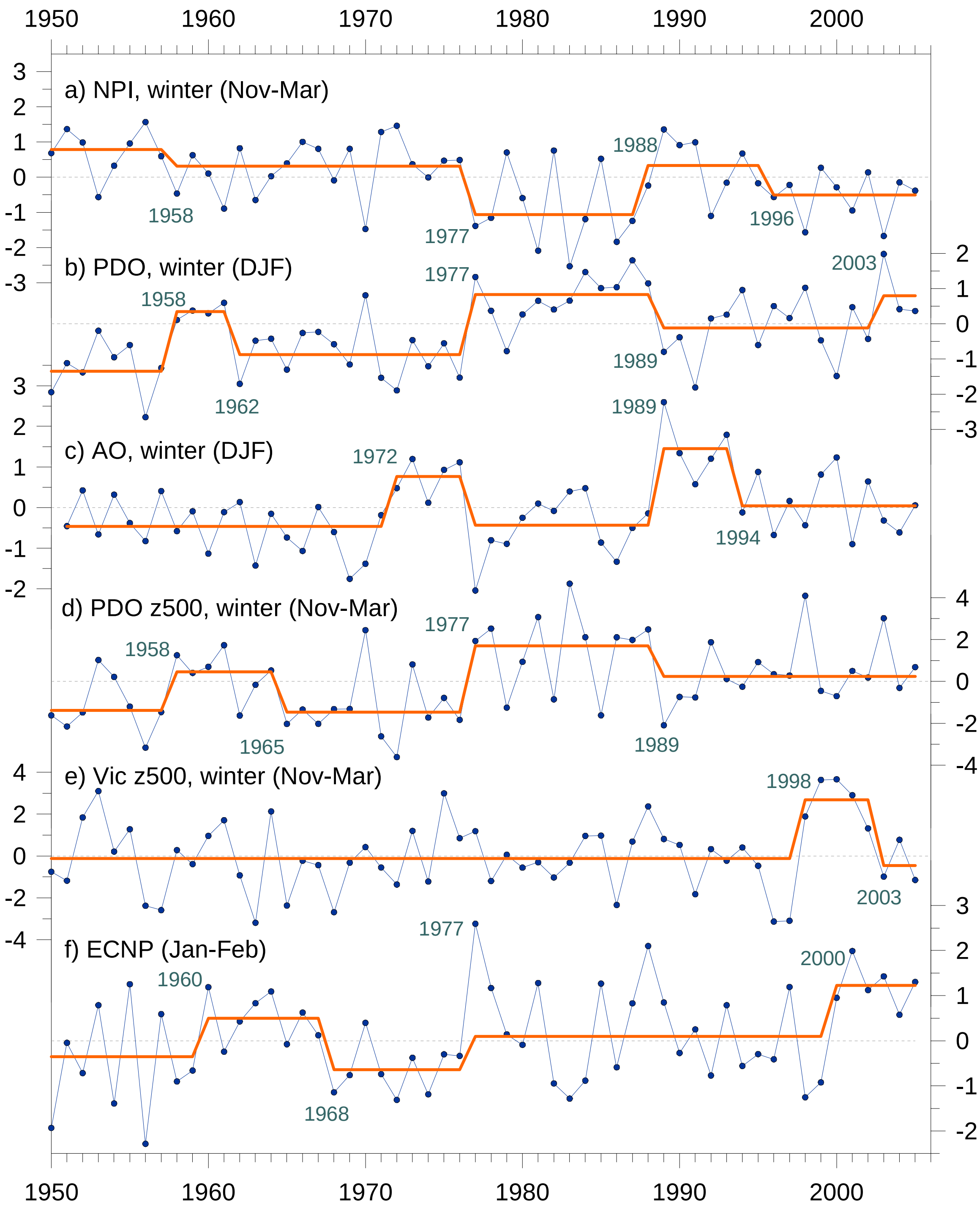
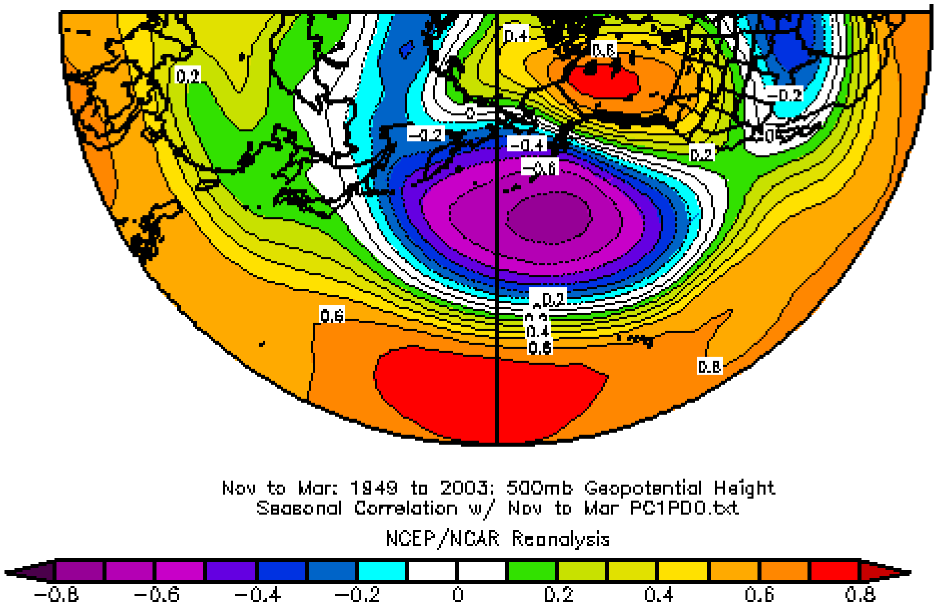


Figure 7. a) Mean winter (Nov-Mar) NPINCAR, 1950-2005, b) Mean winter (DJF) PDO index, 1950-2005, c) Mean winter (DJF) Arctic Oscillation index, 1951-2005, d) Mean winter (Nov-Mar) atmospheric PDO index at the 500-hPa level, 1950-2005, e) Mean winter (Nov-Mar) atmospheric Victoria index at the 500-hPa level, 1950-2005, and f) January-February East-Central North Pacific index, 1950-2005. The stepwise functions (orange lines) characterize regime shifts in the level of fluctuations of the indices. Shift points were calculated using the STARS method (Rodionov 2004), with the cutoff length of 7 years, the maximum significance level of 0.2, and the Huber weight parameter of 1.

a) R [PC1 (PDO) vs. z500]



b) R [PC2 (Victoria) vs. z500]

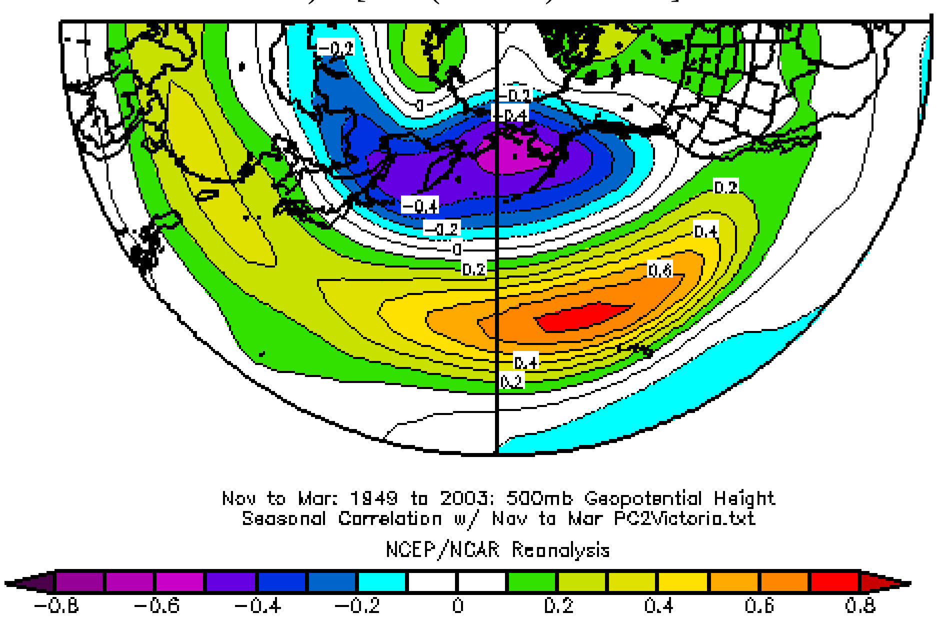


Figure 8. Correlation coefficients between mean winter (Nov-Mar) 500-hPa heights at grid points with (a) PC1 (PDO) and (b) PC2 (Victoria) time series from Figure 3.

It has been shown that the North Pacific atmosphere-ocean system included anomalies during the winter of 2004-05 that were unlike those associated with the primary modes of past variability. This result suggests a combination of two factors: (1) that the nature of North Pacific variability is actually richer in variability than appreciated previously, and (2), that there is the potential for significant evolution in the patterns of variability due to both random, stochastic effects and systematic trends such as global warming. Notably, at the time of this writing, it cannot be determined whether the North Pacific is heading into a positive PDO-like condition or some other state.